METHOD AND APPARATUS FOR ASYNCHRONOUS INCREMENTAL REDUNDANCY TRANSMISSION IN A COMMUNICATION SYSTEM

Background of the Invention

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Related Application

Related subject matter is disclosed in the following application concurrently filed herewith: U.S. Patent Application entitled "Method and Apparatus For Asynchronous

10   Incremental Redundancy Reception In A Communication System", Serial No. _____ .

Field of the Invention

The present invention relates to a method for an Automatic Repeat Request (ARQ) technique for communication systems.

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Description of the Related Art

The quality of communication channels within communication systems determines the efficiency of the communication system. One measure of efficiency is the

20   system's throughput. The throughput is the amount of information that is successfully transmitted and received in a communication system for a defined period of time. It is therefore a goal of service providers (owners and operators of communication systems) to have as many of their communication channels as possible operating at an acceptable throughput.

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In wireless communication systems, the communication channels used by a subscriber of such a system are commonly known as the air interface. The air interface is used for the exchange of information between a mobile (e.g., cell phone) and a base station or other communication system equipment. The air interface comprises a plurality

30   of communication channels. The quality of any one of the channels of the air interface varies. Thus, for example, any particular channel between the base station and a mobile may have an acceptable throughput at one instant and unacceptable throughput at another

instant. Service providers not only want to maintain the throughput of their air interface at an acceptable level, but also want to increase the throughput as much as possible.

Many times the information transmitted through a relatively low quality
5 communication channel is adversely affected to such an extent that the information contains errors when received. In an effort to increase the throughput of such channels, communication systems apply the technique of retransmission of information. Transmitting equipment retransmits the information to receiving equipment a certain number of times to increase the likelihood that the information, once received, contains
10 no errors or contains an acceptable number of errors. The receiving equipment can be either system equipment such as a base station or subscriber equipment such as a cell phone. Similarly, the transmitting equipment can also be system equipment or subscriber equipment. System equipment is any equipment owned and operated by the service provider.
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A widely used technique for the retransmission of information due to errors detected at the receiving equipment is called Automatic Retransmission Request (ARQ). The ARQ method is a technique of confirming that information transmitted through a communication channel has been received without any errors. Receiving equipment
20 sends a message to transmitting equipment confirming that the transmitted information was received without errors. If the transmitted information was received with errors, the receiving equipment sends a message to the transmitting equipment asking the transmitter to retransmit the information. The transmitter can retransmit all or part of the previously transmitted information using the same or different channel coding.
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ARQ is typically used in concert with channel coding. Channel coding is the creation of redundancy in the transmitted information to allow receiving equipment to check as well as correct for errors. Also, the receiving equipment performs a corresponding decoding operation to obtain the information. The decoding operation is
30 performed by a decoder. Two of the main ARQ methods are the Selective Retransmit

(SR) protocol and the Stop-and-Wait protocol. In both SR ARQ and Stop-and-Wait ARQ, the concept of Incremental Redundancy (IR) is used. Incremental Redundancy (IR) and/or soft combining, are techniques used to improve the efficiency of ARQ. In IR, the receiving equipment attempts to combine, in the decoder, retransmitted information

5   along with earlier transmissions of the same information that used the same or different coding. The decoding of combined information improves the performance of the decoding operation and increases the likelihood of successful decoding; decoding of combined information reduces the number of retransmissions that would be required to successfully receive the transmitted information. In the prior art, IR schemes that operate

10   with SR ARQ and with Stop-and-Wait ARQ have been defined.

In the IR scheme operating with SR ARQ, data is typically encoded, formatted and packaged as packets comprising payload, header and trailer portions. The trailer and header portions are overhead in that they do not contain subscriber information; they

15   contain information identifying the subscriber (i.e., identification information) and information on how to process the packet (i.e., process information). The information identifying the particular subscriber from whom the information in the payload of the packet originated is kept in the header. Also, the header contains information on how to soft combine, at the decoder, the received packets so as to properly decode the payload

20   information.

An arbitrary number of copies of each block of information can be sent so that the original information can be derived from one or from a combination of the received packets of information. Different subscribers can transmit different amounts of

25   information and at different rates. As described above, however, much information is needed to describe how the information is to be processed once it is received. The SR protocol is not bandwidth efficient because of the excessive overhead information. However, without the use of the header information, the receiving equipment is not able to identify, and properly combine and decode the received packets of information. To

30   reduce the likelihood that the header information is contaminated resulting in errors, the

header portion of the packets is heavily coded. The heavy coding is more robust coding that requires more redundancy to be added to the header information. Thus, the heavy coding creates even more overhead which reduces the throughput of the communication channels thus reducing the efficiency of the communication system.

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In the IR scheme with Stop-and-Wait ARQ protocol, a block of information is coded into n packets where n is an integer equal to 2 or greater. Each one of the packets by itself or in combination with another packet or a portion of another packet can be used to decode the original block of information . One or more of the packets are transmitted

10   during a time slot(s) assigned to a particular subscriber. The transmitted packets are received and decoded. If the decoding was successful (i.e., no errors detected or an acceptable number of errors detected), the receiving equipment transmits an ACK (ACKnowledge) message to the transmitting equipment indicating that the information was properly decoded and that a new block of information can be transmitted. If the

15   decoding was unsuccessful (i.e., error detected or an unacceptable number of errors detected), the receiving equipment transmits a NACK (Negative ACKnowledge) which is an indication to the transmitting equipment to retransmit another group of packets (or another single packet) representing the same block of information. The ACK message is thus an example of a positive confirmation message and the NACK message is an

20   example of a negative confirmation message. Upon reception of a NACK message the receiving equipment stores the received error-containing packet. The receiving equipment will attempt to combine this stored packet with subsequent repeat packet transmissions for the same block of information, to properly decode the information within such block. The ACK or NACK confirmation messages are hereinafter referred to

25   as the ACK/NACK messages.

The receiving equipment transmits the ACK/NACK message following the reception of a packet in a particular time slot assigned to a subscriber. Thus, the ACK/NACK messages are transmitted in accordance with a particular timing relationship

30   to the packet reception. The transmit equipment associates a particular ACK/NACK

message with a particular packet transmission based on the time slot or the time period within which such a message was received. For example, an ACK/NACK message received during slot period m corresponds to a packet transmission in slot m-k, where k represents a particular number (including fractions of time slots) of time slots which is

5 fixed by the communication system; m is an integer equal to 1 or greater an k is a number greater than zero. The number of time slots represented by k is a roundtrip delay for transmitting equipment representing the time elapsed between a transmission of a packet and the reception of a responding ACK/NACK message.

10 Upon receipt of a NACK(in a particular time slot) in response to a packet transmission, the transmitting equipment transmits a repeat packet representing the same block of information. The transmitting equipment transmits the repeat packet transmission a certain number of time slots following the receipt of the ACK/NACK message. Thus, the repeat packet is transmitted in accordance with a particular timing

15 relationship to the received ACK/NACK message.

The receive equipment associates a particular repeat packet transmission with a ACK/NACK message based on the time slot or the time period within which such a message was received. For example, a repeat packet transmission received during slot

20 period n corresponds to a ACK/NACK message transmitted in slot n-j, where j represents a certain number (including fractions of time slots) of time slots which is fixed by the communication system; n is an integer equal to 1 or greater and j is a number greater than zero. The number of time slots represented by j is a roundtrip delay for receiving equipment representing the time elapsed between the transmission of an ACK/NACK

25 message and the reception of a repeat packet. Therefore, there is no need to transmit identification information in the headers of the packets because the packets can be identified and soft combined based on the time slot in which they were received.

The Stop-and-Wait protocol in the prior art is thus a Synchronous Protocol in that

30 the repeat packet transmission are transmitted within a strict timing relationship (defined

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by the communication system) between transmitting equipment and receiving equipment. Consecutive packet transmissions of the same block of data are separated by a time period usually expressed in terms of number of slots where such time period is constant. In sum, when a transmission is made, an ACK/NACK message indicating a NACK (or

5   ACK) followed by a repeated packet transmission (or a new packet transmission) must be transmitted a certain fixed number of slots later.

The Stop-and-Wait protocol as implemented in the prior art, has several drawbacks stemming from its synchronous nature and the manner in which it is typically

10   implemented. Because of the strict timing relationship imposed on the transmissions, it is very difficult to accommodate different subscribers having different transmission rates or different roundtrip delays. Subscribers having different transmission rates transmit (or receive) information within different number of assigned consecutive time slots. For example, some subscribers use three time slots to transmit (or receive) their block of

15   information while others use only one time slot. The transmission roundtrip delay is the amount of time elapsed between consecutive transmission of packets or group of packets. In the Stop-and-Wait protocol, the transmission roundtrip delay is kept fixed.

When a packet associated with a particular subscriber is transmitted, the

20   transmitting equipment expects to receive an ACK or NACK within a certain number of time slots later, i.e., the ACK/NACK messages have a fixed roundtrip delay. Once the transmitting equipment receives the ACK/NACK message it transmits a new packet or transmits a repeat packet, i.e., a packet containing previously transmitted information. During the time period between transmissions, other transmissions (associated with other

25   subscribers) can occur. However, due to a fixed transmission roundtrip delay, once the number of slots equaling the transmission roundtrip delay has elapsed, the next slot must be used for a new packet or a a repeat packet transmission because the slot is reserved for such purpose. In other words, the other transmissions must be completed prior to the occurrence of the time slot reserved for the transmission of packets associated with a

30   particular subscriber. The transmitting equipment is thus constrained to transmitting

packets at predefined times for a particular subscriber. The constraint on time of transmission removes a great amount of flexibility from the transmitting equipment to transmit information during times of favorable channel conditions. Many communication systems have the capability to monitor the quality of their communication channels. It

5   would be desirable for the transmitting equipment to either postpone or delay the transmission of information through a particular channel until that channel has favorable conditions. In this manner, the communication system can improve its throughput. However, because of the strict timing relationship imposed by the Stop-and-Wait protocol, the transmitting equipment, many times, is unable to take advantage of

10   favorable channel conditions.

Another drawback with the Stop-and-Wait protocol is that it is not adaptable to changing channel conditions because the number of initial transmissions or retransmissions is fixed. In many cases the quality of a communication channel is such

15   that a relatively large number of attempts, i.e., retransmissions, is needed to transmit an initial packet successfully. Depending on the channel conditions, the number of transmissions necessary to successfully transmit a packet may be more than what is allocated for that packet. When the number of attempts surpasses the number allocated, the subscriber is either dropped from the system or the block of information containing

20   errors is accepted raising the error rate of the communication channel.

Therefore, what is needed is an ARQ technique that accommodates different subscribers having different transmission rates, different information lengths and different roundtrip delays. What is further needed is an ARQ technique which allows the

25   transmitting equipment to schedule its transmissions during favorable channel conditions whenever possible so as to increase the throughput of that channel and thus the overall throughput of the communication system.

Summary of the Invention

5   The present invention provides a method which implements an ARQ technique used with Incremental Retransmission (IR) that allows transmitting equipment in a communication system to operate asynchronously. The transmitting equipment applies the information to be transmitted to a scheduling algorithm that determines the time of transmission of information associated with a particular subscriber and the amount of

10   information to be transmitted. The information to be transmitted contains an information status flag indicating whether the information is NEW information or CONTINUE information. The information to be transmitted also contains identification information identifying the particular subscriber associated with the information. The transmitting equipment is thus not only able to schedule its transmissions, but also decide how much

15   information is to be transmitted and how many attempts at a successful transmission is allocated to a particular subscriber. The method of the present invention can be used in wireless communication systems and other types of communication systems.

       The information is preferably packaged into packets. Each packet is coded into a

20   plurality of sub-packets. Each sub-packet has an information status flag in its header. The information status flag indicates whether a sub-packet is the beginning of information (i.e., NEW information) or the continuation of information that is being transmitted (i.e., CONTINUE information). Each sub-packet also contains subscriber identification information to associate the sub-packet to a particular subscriber. Thus, the

25   format of the transmitted sub-packets gives the transmitting equipment the ability to indicate the packet boundaries, i.e., the beginning of each new packet is indicated by the value of the information status flag. Because the packet boundaries are identified and the subscriber associated with each sub-packet is known, the transmitter is able to operate in an asynchronous manner. As a result of being able to operate asynchronously, the

30   transmitter can use various scheduling algorithms to prioritize the transmissions or

retransmissions for different subscribers based on, for example, the conditions of the communication channels through which the sub-packets are transmitted and various other factors.

5   In a preferred embodiment, each sub-packet contains a one-bit NEW/CONTINUE flag as its information status flag. For a particular subscriber, when the beginning of a packet is being transmitted, the information status flag of the corresponding packet is set to NEW. When the continuation of information is being transmitted or when a retransmission is performed, the flag is set to CONTINUE. After the transmission of a

10   sub-packet is performed, the transmitter waits for a confirmation message from corresponding receiving equipment. Preferably, an ACK is used for positive confirmation messages and a NACK is used for negative confirmation messages. Depending on the received confirmation message, the transmitter will either transmit NEW information or CONTINUE information. For the same subscriber, the transmitting

15   equipment will then determine: (a) when to perform the next transmission (b) the information rate of the next transmission and (c) the amount of information to be transmitted (e.g., amount of information contained in a sub-packet) based on the results of a scheduling algorithm to which the information to be transmitted is applied. The transmitting equipment is able to execute a particular scheduling algorithm adopted by

20   the service provider of the communication system.

Brief Description of the Drawings

25   FIG. 1 shows a flowchart depicting the steps of the method of the present invention.

Detailed Description

The present invention provides a method which implements an ARQ technique

30   used with Incremental Retransmission (IR) that allows transmitting equipment in a

communication system to operate asynchronously. The transmitting equipment applies

the information to be transmitted to a scheduling algorithm that determines the time of

transmission of the information associated with a particular subscriber and the amount of

information in the transmission. The information to be transmitted is provided with an

5   information status flag indicating whether the information is NEW or CONTINUE

information. The present invention also provides an apparatus that transmits information

asynchronously by applying the information to a scheduling algorithm that determines the

time of transmission and the amount to be transmitted. The apparatus can be implement

with digital and/or analog hardware, microprocessor and/or digital processor based

10   circuitry used in conjunction with firmware and/or software. The apparatus is configured

to reside in both transmitting equipment and receiving equipment.

Referring to FIG. 1, there is shown the method of the present invention for

transmitting equipment in a communication system that uses ARQ. For ease of

15   explanation, the method of the present invention will be explained in the context of three

packets of information transmitted consecutively whereby each packet is coded and is

then segmented into a plurality of sub-packets. Each sub-packet contains, preferably in

its header, an information status flag indicating whether the sub-packet is NEW

information or CONTINUE information. NEW information is the beginning of

20   information that is being transmitted for the first time. CONTINUE information

represents information that follows the NEW information and is part of the NEW

information. CONTINUE information is thus the continuation of previously transmitted

information or the retransmission of previously transmitted information that was decoded

unsuccessfully. The information status flag is preferably a one-bit NEW/CONTINUE

25   flag where a "0" bit indicates that the sub-packet is CONTINUE information and a "1"

bit indicates that the sub-packet is NEW information. Because the flag uses only one bit,

the coding of this flag does not use much overhead even when heavy coding is used. It

should be noted that the NEW/CONTINUE flag can be stored anywhere in a sub-packet

or in any other type of block of information. Further, the NEW/CONTINUE flag can be

30   more than one bit. For example, the NEW/CONTINUE flag can be implemented with

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two bits wherein each two bit value not only identifies the type of information contained in the sub-packet but also identifies the particular sub-packet in terms of the sequence of sub-packets. The two-bit flag thus assists equipment receiving the sub-packets to perform various operations such as decoding and combining of packets. For example, a

5   two-bit flag for a group of 3 packets may be used as follows:

00 –NEW sub-packet; 01—CONTINUE sub-packet 1; 10—CONTINUE sub-packet 2; 11—CONTINUE sub-packet 3. It should also be noted that the NEW/CONTINUE flag and the identification information may be transmitted separately from the sub-packet payload. For example, the identification information and the

10   information status flag can be transmitted and received on a separate code multiplexed channel in a CDMA (Code Division Multiple Access) communication system, or separate time slots may be reserved for these fields in a TDMA (Time Division Multiple Access) communication system.

15   The three packets of information are A_1, A_2 and A_3 where A_1 is segmented into three sub-packets a_{11}, a_{12} and a_{13}. Similarly, packets A_2 and A_3 are each segmented into three sub-packets a_{21}, a_{22}, a_{23} and a_{31}, a_{32}, a_{33} respectively. Packet A_1 is first transmitted followed by packet A_2 and then packet A_3. It should be noted that each of the sub-packets by themselves or in combination with other sub-packets or other portions of

20   sub-packets can be used to decode the original information contained in the packet.

In step 102 of FIG. 1, a new packet is obtained by the transmitting equipment, i.e., packet A_1 is obtained. In step 104, packet A_1 is encoded and segmented. Any well known coding technique can be used to encode packet A_1 and all following packets. The

25   encoded packet A_1 is segmented into three sub-packets a_{11}, a_{12} and a_{13} where each sub-packet contains a NEW/CONTINUE flag in its header. Each sub-packet also contains identification information. It should be noted that the length of each sub-packet might require more than one time slot for transmission. In step 106, the transmitting equipment sets the flag of sub-packet a_{11} to NEW.

In step 108, the transmitting equipment applies the first sub-packet to be transmitted, i.e., sub-packet a_{11}, to a scheduling algorithm or sub-packet priority scheme that determines when the sub-packet is to be transmitted. The method of the present invention then waits for an interrupt signal in the form of an ACK/NACK message or an interrupt signal from the scheduling algorithm. The scheduling algorithm may, for example, depend on the conditions of the communication channel through which sub-packet a_{11} is to be transmitted. The scheduling algorithm may depend on other factors such as the time of day, the quality of service agreed upon between the service provider and the subscriber associated with packet A_1 or even the availability of communication channels. The scheduling algorithm handles many sub-packets from various subscribers and determines when a particular sub-packet is to be transmitted; the scheduling algorithm generates an interrupt signal (or scheduler request signal) requesting the transmitting equipment to transmit sub-packet a_{11}. Also in step 108 the transmitting equipment is monitoring the communication channel assigned to the subscriber for a confirmation message (e.g., ACK/NACK message) responding to an immediate previous transmission. At this point, an ACK/NACK message is not expected because sub-packet a_{11} is the first sub-packet being transmitted. When an interrupt signal is received the method of the present invention moves to step 110.

In step 110, the method of the present invention determines the type of interrupt signal received, i.e., ACK, NACK or scheduler request. Continuing with our example, the method of the present invention moves to step 114 since the interrupt signal received was a scheduler request. In step 114, the transmitting equipment transmits sub-packet a_{11}. In step 116, the transmitting equipment determines whether the maximum number of transmissions allowed for the subscriber has been reached. The method of the present invention allows each subscriber a maximum number of retransmissions based on various factors such as the quality of service paid by the subscriber, the amount of information being handled by the communication system and the condition of the communication

channel assigned to the subscriber. Other well known factors can be used by the service provider. Suppose the maximum number of retransmissions for the subscriber associated with packet A_1 is 3. Therefore, at this point the method of the present invention moves to step 118 since there has been no retransmissions so far. In step 118, the next sub-packet,

5   i.e., a_{12}, associated with the current packet being transmitted is selected. In step 120 the transmitting equipment sets the NEW/CONTINUE flag of sub-packet a_{12} to CONTINUE. The method of the present invention now moves to step 108 to once again wait for an interrupt. Suppose the transmitted sub-packet a_{11} was received and decoded successfully and consequently an ACK message is transmitted. The ACK message is transmitted

10   indicating that the information contained in sub-packet a_{11} was successfully decoded. Therefore, the transmission of sub-packet a_{11} was a successful transmission. The transmitting equipment detects the message in step 108 and in step 110 determines that the message is an ACK message. The method of the present invention now moves to step 112 where the remaining sub-packets associated with packet A_1 (i.e., sub-packets a_{12} and

15   a_{13}) are discarded.

The method of the present invention now moves to step 102 and selects a new packet A_2. In step 104 packet A_2 is encoded and segmented into sub-packets a_{21}, a_{22} and a_{23}. In step 106 sub-packet a_{21} has its NEW/CONTINUE flag set to NEW. In step 108,

20   sub-packet a_{21} is applied to the scheduling algorithm and the method of the present invention waits for an interrupt signal. In step 110, an interrupt signal has been received and it is determined to be a scheduler request. Accordingly, the method of the present invention moves to step 114 and transmits sub-packet a_{21} and in step 116 determines that the maximum number of retransmissions allocated for this subscriber has not been

25   reached. Suppose the maximum number of retransmissions allocated for the subscriber associated with packet A_2 is 3. Since the number of retransmissions at this point is 0, the method of the present invention moves to step 118 where sub-packet a_{22} is selected. In step 120 the transmitting equipment sets the NEW/CONTINUE flag of sub-packet a_{22} to

CONTINUE and moves to step 108 where it applies sub-packet a_{22} to a scheduling

algorithm and waits for an interrupt signal. An interrupt signal is received and in step

110, it is determined to be a NACK signal. The method of the present invention returns

to step 108 and again waits for an interrupt signal.

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An interrupt signal is again received and it is determined in step 110 to be a

scheduler request. Accordingly, the method of the present invention moves to step 114

where sub-packet a_{22} is transmitted. In step 116, the maximum number has not been

reached since there has been only 1 retransmission associated with packet A_2 thus far.

10   The method of the present invention therefore moves to step 118 where sub-packet a_{23} is

selected and in step 120 the NEW/CONTINUE flag of sub-packet a_{23} is set to

CONTINUE. The method of the present invention moves to step 108 where it applies

sub-packet a_{23} to a scheduling algorithm and waits for interrupt signal, which it receives

at some later time. In step 110, it is determined that the interrupt signal is another NACK

15   signal causing the method of the present invention to return to step 108 to wait for an

interrupt signal. The interrupt signal is received and, in step 110, it is determined to be a

scheduler request causing sub-packet a_{23} to be transmitted in step 114. In step 116, it is

determined that the number of retransmissions thus far is 2 and thus the method of the

present invention moves to step 118 where sub-packet a_{21} is again selected. Note that

20   sub-packet a_{21} is being selected a second time because the method of the present

invention selects the sub-packets in round robin fashion so that the same sub-packets are

selected repeatedly and retransmitted until the maximum number of retransmissions is

reached. In step 120 the NEW/CONTINUE flag of sub-packet a_{21} is set to CONTINUE.

25   The method of the present invention moves to step 108, applies sub-packet a_{21} to

a scheduling algorithm and waits for an interrupt signal. In step 110, the interrupt signal

is determined to be yet another NACK signal causing the method of the present invention

to return to step 108 to wait for another interrupt signal. Upon reception of the interrupt

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signal, the method of the present invention moves to step 110 where it is determined to be a scheduler request. The method of the present invention moves to step 114 where it transmits sub-packet a_{21}. In step 116, it is determined that the number of retransmission is now 3 which is the maximum number allocated for the subscriber associated with

5   packet A_2. Therefore, the method of the present invention moves to step 122 where all sub-packets segmented from packet A_2 are discarded and in step 102 a new packet, i.e., A_3, is selected. At this point, the confirmation message corresponding to the last transmission for packet A_2 is yet to be received. Regardless of whether the confirmation message is a NACK or an ACK, the method of the present invention will not transmit any

10   more transmissions associated with packet A_2. The subscriber may wish to retransmit packet A_2, but only after this packet has been once again coded and applied to the method of the present invention. The sub-packets segmented from packet A_3 are then transmitted in accordance with the method of the present invention as described above.

15   Another version of the method of the present invention allows the transmitting equipment to transmit information based only on interrupt signals from the scheduler algorithm. One or all of the sub-packets segmented from a packet are transmitted upon the receipt of an interrupt signal from the scheduling algorithm. Any confirmation messages (i.e., ACK or NACK) received are ignored. The sub-packets are thus

20   transmitted based on various conditions considered by the scheduling algorithm. The method of the present invention thus performs what is commonly called link adaptation. Link adaptation is the use of communication channels at instants of time determined to be most favorable when various factors are taken into consideration. The various factors are typically channel parameters that give some type of indication of the quality of the

25   communication channel.